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L. L. Thomas

lorithomas@k-state.edu, lorithomas@k-state.edu

R. D. Goodband

Kansas State University, Manhattan, goodband@k-state.edu

C. D. Espinosa

Department of Animal Sciences, University of Illinois, Urbana-Campaign, IL

See next page for additional authors

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Evaluation of the Effects of High-Lysine Sorghum on Nursery Pig Performance

Abstract

Two experiments were conducted to determine the standardized ileal digestibility (SID) of amino acids in a high-lysine sorghum cultivar, followed by a growth trial to determine the effect of this sorghum on pig performance using increasing additions of feed-grade amino acids at the expense of soybean meal. In Exp. 1, ten growing barrows (initially 57.1 lb; Line 359 × 1050; PIC, Hendersonville, TN) were surgically fitted with a T-cannula at the terminal ileum and randomly assigned to 1 of 5 test diets in a 5-period, cross-over design. Experimental diets consisted of a corn-based diet, a diet containing high-lysine sorghum, or two diets with either white or red sorghum cultivars. The grain sources were the only protein sources included in these experimental diets. The fifth experimental diet was N-free for determining basal endogenous amino acid loss. All diets contained 0.40% chromic oxide as an indigestible marker. Standardized ileal digestible crude protein, lysine, methionine, threonine, and valine were greater ($P < 0.020$) in corn than in the sorghum-based diets with no evidence for differences among the three sorghum cultivars.

In Exp. 2, a total of 293 pigs (initially 21.3 lb; Line 241 × 600; DNA, Columbus, NE) were used in a 20-d growth trial. On d 20 after weaning, considered d 0 in the trial, pens were randomly assigned to 1 of 6 dietary treatments with 10 replications per treatment. Treatments consisted of a corn-based diet, a diet based on conventional sorghum (a mixture of red and white sorghum), and 4 diets with high-lysine sorghum. The corn-based, conventional sorghum, and the first high-lysine sorghum diets each contained the same amount of soybean meal with varying amounts of feed-grade amino acids. The 3 remaining high-lysine sorghum diets included incrementally increasing amounts of feed-grade amino acids, replacing soybean meal. Overall, there was no evidence for differences in average daily gain (ADG) or average daily feed intake (ADFI) among dietary treatments. However, pigs fed the high-lysine sorghum with the greatest amount of added feed-grade amino acids had the poorest feed-to-gain ratio (F/G) ($P = 0.05$) compared with those fed other experimental diets.

In summary, SID amino acid values for the high-lysine sorghum used in this study were not different from either red or white sorghum cultivars; however, these values were all lower when compared with corn. When swine diets for nursery pigs were formulated on an SID amino acid basis, there were no differences in ADG among pigs fed any of the various diets. High-lysine sorghum is a viable alternative grain source in swine diets and can be used with feed-grade amino acids to reduce the amount of soybean meal in the diet, potentially lowering feed cost. Research is needed to determine the maximum inclusion of feed-grade amino acids in nursery pig diets without negatively impacting F/G.

Keywords

High-lysine sorghum, corn, feed-grade amino acids, nursery pigs

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Authors

L. L. Thomas, R. D. Goodband, C. D. Espinosa, H. H. Stein, J. C. Woodworth, M. D. Tokach, S. S. Dritz, and

J. M. DeRouchey

Evaluation of the Effects of High-Lysine Sorghum on Nursery Pig Performance¹

*L.L. Thomas, R.D. Goodband, C.D. Espinosa,² H.H. Stein,²
J.C. Woodworth, M.D. Tokach, S.S. Dritz,³ and J.M. DeRouchey*

Summary

Two experiments were conducted to determine the standardized ileal digestibility (SID) of amino acids in a high-lysine sorghum cultivar, followed by a growth trial to determine the effect of this sorghum on pig performance using increasing additions of feed-grade amino acids at the expense of soybean meal.

In Exp. 1, ten growing barrows (initially 57.1 lb; Line 359 × 1050; PIC, Hendersonville, TN) were surgically fitted with a T-cannula at the terminal ileum and randomly assigned to 1 of 5 test diets in a 5-period, cross-over design. Experimental diets consisted of a corn-based diet, a diet containing high-lysine sorghum, or two diets with either white or red sorghum cultivars. The grain sources were the only protein sources included in these experimental diets. The fifth experimental diet was N-free for determining basal endogenous amino acid loss. All diets contained 0.40% chromic oxide as an indigestible marker. Standardized ileal digestible crude protein, lysine, methionine, threonine, and valine were greater ($P < 0.020$) in corn than in the sorghum-based diets with no evidence for differences among the three sorghum cultivars.

In Exp. 2, a total of 293 pigs (initially 21.3 lb; Line 241 × 600; DNA, Columbus, NE) were used in a 20-d growth trial. On d 20 after weaning, considered d 0 in the trial, pens were randomly assigned to 1 of 6 dietary treatments with 10 replications per treatment. Treatments consisted of a corn-based diet, a diet based on conventional sorghum (a mixture of red and white sorghum), and 4 diets with high-lysine sorghum. The corn-based, conventional sorghum, and the first high-lysine sorghum diets each contained the same amount of soybean meal with varying amounts of feed-grade amino acids. The 3 remaining high-lysine sorghum diets included incrementally increasing amounts of feed-grade amino acids, replacing soybean meal. Overall, there was no evidence for differences in average daily gain (ADG) or average daily feed intake (ADFI) among dietary treatments. However, pigs fed the high-lysine sorghum with the greatest amount of added feed-grade amino acids had the poorest feed-to-gain ratio (F/G) ($P = 0.05$) compared with those fed other experimental diets.

¹The authors wish to thank the Collaborative Sorghum Investment Program, Kansas State University, Manhattan for partial financial support for this project.

²Department of Animal Sciences, University of Illinois, Urbana-Campaign, IL.

³Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University.

In summary, SID amino acid values for the high-lysine sorghum used in this study were not different from either red or white sorghum cultivars; however, these values were all lower when compared with corn. When swine diets for nursery pigs were formulated on an SID amino acid basis, there were no differences in ADG among pigs fed any of the various diets. High-lysine sorghum is a viable alternative grain source in swine diets and can be used with feed-grade amino acids to reduce the amount of soybean meal in the diet, potentially lowering feed cost. Research is needed to determine the maximum inclusion of feed-grade amino acids in nursery pig diets without negatively impacting F/G.

Introduction

Sorghum is an excellent energy source that has received considerable attention as an alternative grain source in swine diets. Sorghum, like corn, is first limiting in lysine for pigs but is second limiting in threonine.^{4,5,6} Depending on the cultivar, crude protein content of sorghum may vary from 6.8 to 19.6%⁷ and can have high concentrations of essential amino acids. We speculate that specific high-lysine cultivars of sorghum combined with feed-grade amino acids can replace a portion of soybean meal and potentially lower feed costs without influencing performance. Therefore, the first objective of this study was to determine the standardized ileal digestibility (SID) of amino acids in high-lysine sorghum, as well as white or red sorghum cultivars compared with corn. The second objective was to determine the effect of high-lysine sorghum and increasing additions of feed-grade amino acids on nursery pig growth performance.

Procedures

The University of Illinois and Kansas State University Institutional Animal Care and Use Committees approved the protocols used in these experiments.

Experiment 1 was conducted at the University of Illinois (Urbana-Champaign) Swine Research Center. One source of high-lysine sorghum, red sorghum, white sorghum, and yellow dent corn were obtained and ground to 500 microns. Dry matter, crude protein (CP), and amino acids were analyzed on all grain sources (University of Missouri Agricultural Experiment Station Chemical Laboratory, Columbia, MO, Table 1).

Ten growing barrows (57.1 lb) were fitted with a T-cannula in the distal ileum and were randomly allotted to 1 of 5 test diets in a 5-period design with 2 replicate pigs per diet in each period for a total of 10 replicates per diet. The first diet contained 94.0% corn, and the other diets contained 94.2% of high-lysine, red or white sorghum cultivars. In each of these diets, corn or sorghum were the only source of amino acids (Table 2). The fifth diet was a N-free diet that was used for determining basal amino acid endogenous losses from the small intestine. All diets were formulated to meet or exceed current

⁴Cervantes-Ramirez, M.G., L. Cromwell, and T.S. Stahly. 1991. Amino acid supplementation of a low-protein, grain sorghum-soybean meal diet for growing pigs. *J. Anim. Sci.* 69(Suppl. 1):364 (Abstr.).

⁵Hansen, J.A., D.A. Knabe, and K.B. Burgoon. 1993b. Amino acid supplementation of low-protein sorghum-soybean meal diets for 20- to 50-kilogram swine. *J. Anim. Sci.* 71:442.

⁶Page, T.G., L.L. Southern, and K.L. Watkins. 1993. Threonine supplementation of low-protein, lysine-supplemented sorghum-soybean meal diets for growing-finishing swine. *Livest. Prod. Sci.* 34:153.

⁷Brudevold, A.B. and L.L. Southern. 1994. Low-protein, crystalline amino acid-supplemented, sorghum-soybean meal diets for the 10- to 20-kilogram pig. *J. Anim. Sci.* 72:638-647.

vitamin and mineral requirement estimates⁸ and contained 0.40% chromic oxide as an indigestible marker. Complete diet samples were obtained and stored for later analysis (Table 3).

Pigs were housed in individual pens (4.0 × 4.9 ft) with a nipple drinker that allowed for unlimited access to water. Pens had smooth sides and fully slatted tribar floors. Each pig was weighed at the beginning of each period before being fed the next dietary treatment to determine the amount of feed needed per day at a level 3.2 times the estimated maintenance requirement⁸ for energy. Pigs were also weighed at the conclusion of the experiment. Daily feed allocation was recorded. Each period consisted of a 5-d adaptation during which a supplemental amino acid mixture was added to dietary treatments (Table 4). On d 6 and 7, the supplemental amino acid mixture was not provided and dietary treatments were the only source of amino acids. Ileal digesta collection occurred on d 6 and 7 for 8 h each day. Digesta samples were collected by attaching a plastic bag to the cannula barrel and digesta flowing into the bag was collected. The plastic bags were removed every 30 minutes or as soon as they became full. Thereafter, the collected samples were immediately frozen at -4°F to prevent any bacterial degradation of the amino acid in the digesta. Feed was withdrawn at the end of each period before giving the next experimental diet the following morning to avoid any carryover effects.

At the conclusion of Exp. 1, digesta samples from each pig were thawed, mixed within animal and diet, and sub-sampled for chemical analysis. Digesta samples were lyophilized and finely ground for chemical analysis. Digesta samples, grain ingredient samples, and complete diet samples were analyzed for dry matter, chromium, crude protein, and amino acids according to the AOAC procedures⁹ and apparent ileal digestibility (AID) and SID values (Tables 5 and 6) were calculated based on methods from Stein et al.¹⁰

Experiment 2 was conducted at the Kansas State University Swine Teaching and Research Center in Manhattan, KS. A total of 293 pigs (initially 21.3 lb; Line 241 × 600; DNA, Columbus, NE) were used in a 20-d growth trial. Pigs were weaned at approximately 21 d of age and moved to the nursery. Pigs were randomly allotted to pens of 5 based on their initial body weight (BW). Pigs were fed a common diet for 20 d after weaning. On d 20 after weaning, considered d 0 in the trial, pens were randomly assigned to 1 of 6 dietary treatments with 10 replications per treatment.

Experimental treatments included a corn-based diet, a diet based on conventional sorghum, and 4 diets with high-lysine sorghum. The corn-based, conventional sorghum, and the first high-lysine sorghum (low) diets were formulated to contain the same amount of soybean meal, each with varying amounts of feed-grade amino acids. The 3 remaining high-lysine diets (low-med, med-high, and high) included incrementally increasing amounts of feed-grade amino acids, at the expense of soybean meal. Corn and soybean meal were analyzed for amino acid profile (University of Missouri Agricultural Experiment Station Chemical Laboratory, Columbia, MO) and diets were formulated

⁸NRC 2012. Nutrient Requirements of Swine, 11th ed. Natl. Acad. Press, Washington D.C

⁹AOAC. 2007. Official methods of analysis of AOAC int. 18th ed. Rev. 2. ed. AOAC Int., Gaithersburg, MD, USA.

¹⁰Stein, H. H., B. Sève, M. F. Fuller, P. J. Moughan, and C. F. M. de Lange. 2007. Invited review: Amino acid bioavailability and digestibility in pig feed ingredients: Terminology and application. J. Anim. Sci. 85:172-180. doi:10.2527/jas.2005-742

from these values. The conventional sorghum used in this study was a 50:50 blend of red and white and an average of the analyzed amino acid values was used in formulation. Diets with conventional sorghum cultivars and high-lysine sorghum were formulated based on the SID results obtained in Exp. 1. Other treatment diets were formulated using SID coefficients from NRC⁸ for the corn and SBM. All diets were fed in meal form and formulated to the same Lys:NE ratio (Table 7). Treatments were fed for 20 d. Each pen was equipped with a 4-hole, dry self-feeder and nipple waterer to provide *ad libitum* access to feed and water. Pens of pigs were weighed and feed disappearance was recorded on d 0, 7, 14, and 20 to determine ADG, ADFI, and F/G.

In Exp. 2, all experimental diets were manufactured at the Kansas State University O.H. Kruse Feed Technology Innovation Center, Manhattan, KS. Complete diet samples were taken from 5 feeders per dietary treatment 3 times throughout the study. Samples were stored at -4°F until they were homogenized, subsampled, and submitted (Ward Laboratories, Inc., Kearney, NE) for analysis of dry matter, crude protein, calcium, phosphorus, ether extract, and ash. In addition, amino acid analysis was evaluated at the University of Missouri Agricultural Experiment Station Chemical Laboratory (Columbia, MO; Table 8).

In Exp. 1, the data were analyzed using the PROC MIXED procedure of SAS (version 9.4, SAS Institute Inc., Cary, NC). The model included grain source as a fixed effect and pigs and period as random effects. In Exp. 2, the data were analyzed as a randomized complete block design using the GLIMMIX procedure of SAS with pen as the experimental unit. Weight block was included in the model as a random effect. Estimated means and corresponding standard errors (SEM) are reported. Pairwise comparisons were conducted using a Tukey adjustment to prevent inflation of Type I error due to multiple comparisons. All results were considered significant at $P \leq 0.05$ and marginally significant between $P > 0.05$ and $P \leq 0.10$.

Results and Discussion

Analysis of all manufactured diets (Tables 3 and 8) resulted in values consistent with formulation.

In Exp. 1, amino acid analysis of the grain sources showed that most amino acids, with the exception of lysine, were present in greater concentrations in the high-lysine sorghum compared to the other cultivars of sorghum and corn (Table 1). Crude protein was also greater in the high-lysine sorghum compared to the other grain sources.

In Exp. 1, AID of CP was greatest ($P < 0.05$) for high-lysine sorghum compared to other cultivars of sorghum (Table 5). The AID values for histidine and valine were greater ($P < 0.05$) in high-lysine sorghum compared to the other two cultivars of sorghum with the AID for most other indispensable and dispensable amino acids tending to be greater ($P < 0.100$) for corn compared to the cultivars of sorghum.

When accounting for endogenous N losses to determine standardized ileal digestibility values, digestibility of crude protein was greater for corn ($P < 0.05$) compared to the sorghum cultivars, with no evidence for differences between the different cultivars of sorghum (Table 6). The SID coefficients for leucine, lysine, methionine, phenylala-

nine, threonine, valine, and most dispensable amino acids were greatest for corn ($P < 0.05$), with no evidence for differences among the different cultivars of sorghum. This is expected as sorghum is known to have lower digestibility of protein and amino acids compared to corn.¹¹ In comparison to the NRC,⁸ SID coefficients for corn were higher for most indispensable and dispensable amino acids. Similarly, for the different cultivars for sorghum, the SID coefficients for most indispensable and dispensable amino acids were higher than what is reported in the NRC.⁸

In Exp. 2, there was no evidence for difference in ADG, ADFI, or final BW among dietary treatments for the 20-d study (Table 9). Pigs fed the high-lysine sorghum with the low- and medium-low addition of feed-grade amino acids had the best ($P = 0.05$) F/G compared with those fed the high-lysine sorghum with the greatest feed grade amino acid inclusion, with others intermediate. We speculate that dispensable amino acids may have become limiting as the amount of soybean meal in the diet decreased, resulting in a reduction in dietary crude protein. Previous research suggests the ratio of 6.35 g SID Lys/g crude protein as a threshold value, thereafter dispensable amino acids may limit performance.¹²

In conclusion, there was no evidence the SID amino acid values for the high-lysine sorghum cultivar used in this study were different from the red or white sorghum cultivars. Regardless of the cultivar of sorghum, corn had the greatest SID amino acid digestibility coefficient values. The data herein suggests that pigs fed corn-, conventional sorghum-, or high-lysine sorghum-based diets formulated on a SID amino acid basis have similar ADG and ADFI. This suggests that the use of high-lysine sorghum and feed-grade amino acids could replace a portion of SBM, potentially reducing feed costs in swine diets. Additional research is warranted to determine if other amino acids were limiting in the highest feed grade amino acid addition and if this was indeed the reason for the poorer feed efficiency.

¹¹Urriola, P. E., D. Hoehles, C. Pedersen, H. H. Stein, and G. C. Shurson. Amino acid digestibility of distillers dried grains with solubles, produced from sorghum, a sorghum-corn blend, and corn fed to growing pigs. 2009. J. Anim. Sci. 87:2574-2580. doi:10.2527/jas.2008-1436.

¹²Millet, S., M. Aluwe, J. D. Boever, B. D. Witte, L. Doudah, A. V. Broeke, F. Leen, C. D. Cuyper, B. Ampe, S. D. Campeneere. 2018. The optimal SID lysine: crude protein ratio for maximal nitrogen efficiency in piglets. ASAS World Conference, July 2018, Vancouver, Canada.

Table 1. Chemical analysis of yellow dent corn and different sources of sorghum (% as-fed basis)¹

Item	Corn	Source of sorghum		
		High-lysine	Red	White
Crude protein, %	6.46	13.92	9.49	8.38
Dry matter, %	87.09	90.00	88.55	87.76
Indispensable amino acid, %				
Arginine	0.33	0.43	0.35	0.28
Histidine	0.20	0.31	0.23	0.18
Isoleucine	0.25	0.62	0.41	0.36
Leucine	0.76	2.08	1.29	1.15
Lysine	0.28	0.26	0.24	0.20
Methionine	0.14	0.19	0.16	0.16
Phenylalanine	0.32	0.80	0.52	0.44
Threonine	0.24	0.42	0.32	0.27
Tryptophan	0.07	0.11	0.09	0.09
Valine	0.32	0.71	0.51	0.43
Dispensable amino acid, %				
Alanine	0.47	1.38	0.89	0.80
Aspartic acid	0.48	0.94	0.65	0.58
Cysteine	0.16	0.24	0.19	0.16
Glutamic acid	1.19	3.16	1.98	1.76
Glycine	0.27	0.38	0.32	0.27
Serine	0.31	0.54	0.40	0.35
Tyrosine	0.19	0.38	0.28	0.22
All amino acids	6.70	14.39	9.85	8.61

¹Multiple samples were collected from each ingredient, homogenized, and then subsampled for analysis at Ward Laboratories, Inc. (Kearney, NE) for proximate analysis, and the University of Missouri Agricultural Experiment Station Chemical Laboratory (Columbia, MO) for amino acid analysis performed in duplicate.

Table 2. Diet composition, Exp. 1 (as-fed basis)¹

		Source of sorghum			
Item	Corn	High-lysine	Red	White	N-free
Ingredient, %					
Corn	94.00	---	---	---	---
High-lysine sorghum	---	94.20	---	---	---
Red sorghum	---	---	94.20	---	---
White sorghum	---	---	---	94.20	---
Soybean oil	3.00	3.00	3.00	3.00	4.00
Solka floc	---	---	---	---	4.00
Dicalcium phosphate	1.20	1.10	1.10	1.10	1.65
Calcium carbonate	0.70	0.60	0.60	0.60	0.35
Cornstarch	---	---	---	---	68.30
Sucrose	---	---	---	---	20.00
Chromic oxide	0.40	0.40	0.40	0.40	0.40
Magnesium oxide	---	---	---	---	0.10
Potassium carbonate	---	---	---	---	0.40
Salt	0.40	0.40	0.40	0.40	0.40
Vitamin-mineral premix ²	0.30	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00

¹Ten growing barrows (57.1 lb) were fitted with a T-cannula in the distal ileum and were randomly allotted to 1 of 5 test diets in a 5-period design with 2 replicate pigs per diet in each period for a total of 10 replicates per pig diet.

²The vitamin-micromineral premix provided the following quantities of vitamins and microminerals per pound of complete diet: Vitamin A as retinyl acetate, 11,128 IU; vitamin D₃ as cholecalciferol, 2,204 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfite, 0.644 mg; thiamin as thiamine mononitrate, 0.109 mg; riboflavin, 2.985 mg; pyridoxine as pyridoxine hydrochloride, 0.109 mg; vitamin B₁₂, 0.014 mg; D-pantothenic acid as D-calcium pantothenate, 10.659 mg; niacin as nicotinamide and nicotinic acid, 19.958 mg; folic acid, 0.717 mg; biotin, 0.199 mg; Cu, 4.536 mg as copper sulfate; Fe, 56.699 mg as iron sulfate; I, 0.572 mg as potassium iodate; Mn, 27.216 mg as manganese sulfate; Se, 0.136 mg as sodium selenite; and Zn, 45.359 mg as zinc oxide.

Table 3. Chemical analysis of diets, Exp. 1 (% as-fed basis)¹

Item	Corn	Source of sorghum			N-free
		High-lysine	Red	White	
Crude protein, %	7.10	13.24	8.78	7.80	0.41
Dry matter, %	87.51	90.12	87.64	88.23	94.45
Indispensable amino acid, %					
Arginine	0.35	0.40	0.31	0.29	0.01
Histidine	0.21	0.29	0.21	0.17	0.00
Isoleucine	0.26	0.58	0.38	0.33	0.01
Leucine	0.77	1.93	1.19	1.05	0.03
Lysine	0.29	0.24	0.22	0.20	0.01
Methionine	0.15	0.18	0.15	0.14	0.01
Phenylalanine	0.34	0.75	0.48	0.42	0.01
Threonine	0.26	0.40	0.29	0.26	0.01
Tryptophan	0.03	0.11	0.07	0.06	0.01
Valine	0.34	0.66	0.46	0.41	0.01
Dispensable amino acid, %					
Alanine	0.49	1.29	0.82	0.73	0.02
Aspartic acid	0.54	0.89	0.60	0.54	0.02
Cysteine	0.16	0.22	0.17	0.14	0.00
Glutamic acid	1.24	2.94	1.82	1.60	0.03
Glycine	0.30	0.36	0.30	0.27	0.01
Serine	0.31	0.50	0.37	0.32	0.01
Tyrosine	0.20	0.35	0.24	0.23	0.01
All amino acids	7.04	13.46	9.03	8.00	0.38

¹Multiple samples were collected from each diet, homogenized, and then subsampled for analysis at Ward Laboratories, Inc. (Kearney, NE) for proximate analysis, and the University of Missouri Agricultural Experiment Station Chemical Laboratory (Columbia, MO) for amino acid analysis performed in duplicate.

Table 4. Composition of amino acid mixture¹

Amino acid	Percent
Glycine	57.92
L-Lysine HCl	13.51
DL-Methionine	4.44
L-Threonine	5.79
L-Tryptophan	1.35
L-Isoleucine	4.25
L-Valine	4.83
L-Histidine	2.12
L- Phenylalanine	5.79
Total	100.00

¹One hundred grams of this amino acid mixture was supplemented to dietary treatments daily, during the adaptation period (initial 5 days).

Table 5. Apparent ileal digestibility of amino acids in yellow dent corn and different sources of sorghum^{1,2,3}

Item	Corn	Source of sorghum			SEM
		High-lysine	Red	White	
Crude protein, %	66.8 ^{ab}	70.1 ^a	60.4 ^{bc}	60.0 ^c	2.48
Indispensable amino acid, %					
Arginine	79.0 ^a	75.4 ^{ab}	70.7 ^{bc}	69.8 ^c	1.90
Histidine	80.2 ^a	74.4 ^a	65.0 ^b	65.0 ^b	3.06
Isoleucine	78.2 ^a	77.3 ^{ab}	71.5 ^b	71.1 ^b	2.60
Leucine	83.6 ^a	81.5 ^{ab}	75.8 ^c	77.6 ^{bc}	2.35
Lysine	63.3 ^a	46.1 ^b	42.3 ^b	43.7 ^b	3.72
Methionine	85.6 ^a	78.1 ^b	75.3 ^b	76.3 ^b	2.15
Phenylalanine	80.6 ^a	78.5 ^{ab}	73.2 ^b	73.9 ^b	2.51
Threonine	67.8 ^x	64.2 ^{xy}	58.1 ^y	55.8 ^y	3.87
Tryptophan	49.1 ^b	72.8 ^a	69.8 ^a	65.6 ^a	2.94
Valine	74.0 ^a	72.7 ^a	66.2 ^b	66.0 ^b	2.93
Total ⁴	78.4 ^a	78.9 ^a	73.0 ^b	73.0 ^b	2.24
Dispensable amino acid, %					
Alanine	78.3 ^x	78.6 ^x	72.3 ^y	73.4 ^{xy}	2.28
Aspartic acid	77.3 ^a	73.3 ^{ab}	68.2 ^{bc}	66.4 ^c	2.59
Cysteine	75.9 ^a	69.4 ^{ab}	61.4 ^{bc}	59.7 ^c	3.34
Glutamic acid	83.8 ^a	81.6 ^{ab}	75.9 ^c	77.5 ^{bc}	2.14
Glycine	44.4 ^a	42.6 ^a	35.4 ^{ab}	26.2 ^b	4.56
Serine	77.7 ^a	75.3 ^{ab}	71.1 ^b	69.6 ^b	2.48
Tyrosine	77.8 ^a	71.6 ^{ab}	66.1 ^b	69.1 ^b	2.82
Total ⁵	72.8 ^a	70.5 ^a	62.8 ^b	62.5 ^b	2.84
All amino acids	75.8 ^a	75.1 ^a	68.4 ^b	68.3 ^b	2.50

¹Ten growing barrows (57.1 lb) were fitted with a T-cannula in the distal ileum and were randomly allotted to 1 of 5 test diets in a 5-period design with 2 replicate pigs per diet in each period for a total of 10 replicates per pig diet.

²Values with different superscripts a, b, c differ, $P < 0.05$.

³Values with different superscripts x, y differ, $P < 0.10$.

⁴Total indispensable amino acid (IAA) = $[1 - (\text{total IAA in the digesta} / \text{total IAA in the diet}) \times (\text{marker in the diet} / \text{marker in the digesta})] \times 100$.

⁵Total dispensable amino acid (DAA) = $[1 - (\text{total DAA in the digesta} / \text{total DAA in the diet}) \times (\text{marker in the diet} / \text{marker in the digesta})] \times 100$.

Table 6. Standardized ileal digestibility of amino acids in yellow dent corn and different sources of sorghum^{1,2,3}

Item	Corn	Source of sorghum			SEM
		High-lysine	Red	White	
Crude protein, %	92.8 ^a	84.5 ^b	81.5 ^b	81.9 ^b	2.48
Indispensable amino acid, %					
Arginine	91.8 ^x	87.0 ^x	85.2 ^y	85.4 ^y	1.90
Histidine	88.2 ^a	80.4 ^b	73.1 ^c	75.0 ^{bc}	3.05
Isoleucine	87.5 ^a	81.6 ^{ab}	77.9 ^b	78.5 ^b	2.60
Leucine	89.7 ^a	83.9 ^b	79.7 ^b	82.0 ^b	2.35
Lysine	82.7 ^a	70.2 ^b	67.9 ^b	72.1 ^b	3.72
Methionine	90.4 ^a	82.2 ^b	80.1 ^b	81.4 ^b	2.15
Phenylalanine	89.5 ^a	82.7 ^b	79.5 ^b	81.2 ^b	2.51
Threonine	86.4 ^a	76.7 ^b	74.9 ^b	74.6 ^b	3.87
Tryptophan	84.6	82.7	85.1	83.5	2.94
Valine	87.2 ^a	79.6 ^b	76.0 ^b	77.0 ^b	2.93
Total ⁴	88.9 ^a	84.2 ^{ab}	80.8 ^b	81.9 ^b	2.24
Dispensable amino acid, %					
Alanine	91.4 ^a	83.7 ^b	80.2 ^b	82.3 ^b	2.28
Aspartic acid	89.9 ^a	81.2 ^b	79.5 ^b	79.0 ^b	2.59
Cysteine	86.4 ^a	77.2 ^b	71.3 ^b	71.8 ^b	3.34
Glutamic acid	83.8 ^a	81.6 ^b	75.9 ^b	77.5 ^b	2.14
Glycine	87.1	79.2	78.2	74.1	4.56
Serine	91.6 ^a	84.2 ^b	82.8 ^b	83.2 ^b	2.48
Tyrosine	87.8 ^a	77.6 ^b	74.5 ^b	77.9 ^b	2.82
Total ⁵	88.2 ^a	78.7 ^b	74.9 ^b	76.2 ^b	2.84
All amino acids	88.6 ^a	81.8 ^b	78.1 ^b	79.3 ^b	2.50

¹Ten growing barrows (57.1 lb) were fitted with a T-cannula in the distal ileum and were randomly allotted to 1 of 5 test diets in a 5-period design with 2 replicate pigs per diet in each period for a total of 10 replicates per pig diet.

²Values with different superscripts a, b, c differ, $P < 0.05$.

³Values with different superscripts x, y differ, $P < 0.10$.

⁴Total indispensable amino acid (IAA) = $[1 - (\text{total IAA in the digesta} / \text{total IAA in the diet}) \times (\text{marker in the diet} / \text{marker in the digesta})] \times 100$.

⁵Total dispensable amino acid (DAA) = $[1 - (\text{total DAA in the digesta} / \text{total DAA in the diet}) \times (\text{marker in the diet} / \text{marker in the digesta})] \times 100$.

Table 7. Diet composition, Exp. 2, (as-fed basis)¹

			High-lysine sorghum			
Item	Corn	Sorghum	Low	Low-medium	Medium-high	High
Ingredient, %						
Corn	59.55	---	---	---	---	---
Conventional sorghum	---	59.10	---	---	---	---
High-lysine sorghum	---	---	59.15	62.30	66.75	73.55
Soybean meal, 46.5% CP	34.70	34.65	34.65	31.70	27.50	21.05
Choice white grease	2.25	2.70	2.73	2.35	1.85	1.00
Calcium carbonate	0.95	0.96	0.96	0.96	0.94	0.93
Monocalcium phosphate, 21%	0.98	0.95	0.95	0.95	1.00	1.08
Salt	0.60	0.60	0.60	0.60	0.60	0.60
L-Lysine HCl	0.30	0.35	0.36	0.45	0.58	0.78
DL-Methionine	0.13	0.16	0.12	0.15	0.18	0.24
L-Threonine	0.12	0.13	0.08	0.12	0.17	0.25
L-Tryptophan	0.02	0.001	---	---	0.02	0.06
L-Valine	0.02	---	---	---	---	0.08
Trace mineral	0.15	0.15	0.15	0.15	0.15	0.15
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25
Phytase ²	0.02	0.02	0.02	0.02	0.02	0.02
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis						
Standardized ileal digestible (SID) amino acid, %						
Lysine	1.30	1.30	1.30	1.30	1.30	1.30
Isoleucine:lysine	64	66	74	71	66	59
Leucine:lysine	128	131	164	161	157	150
Methionine:lysine	33	34	32	33	34	36
Methionine and cysteine:lysine	56	56	56	56	56	56
Threonine:lysine	63	63	63	63	63	63
Tryptophan:lysine	19.1	19.2	20.1	19.0	19.0	19.1
Valine:lysine	70	69	77	74	70	70
SID lysine:net energy, g/Mcal	5.23	5.23	5.23	5.23	5.23	5.23
SID lysine:crude protein, g/kg	5.9	5.8	5.8	6.0	6.4	7.2
Total lysine, %	1.47	1.46	1.46	1.45	1.44	1.43
Net energy, kcal/lb	1,127	1,127	1,127	1,127	1,127	1,127
Crude protein, %	21.9	22.3	22.5	21.6	20.2	18.1
Calcium, %	0.73	0.73	0.73	0.72	0.71	0.70
Phosphorus, %	0.61	0.61	0.61	0.60	0.59	0.58
Available phosphorus, %	0.38	0.38	0.38	0.38	0.39	0.40

¹Diets were fed from 21.3 to 46.2 lb body weight, respectively.²HiPhos 2700 (DSM Nutritional Products, Parsippany, NJ) provided an estimated release of 0.10% STTD P.

Table 8. Chemical analysis and amino acid analysis of experimental diets fed to nursery pigs (as-fed basis)¹

Item	Corn	Sorghum	High-lysine sorghum			
			Low	Low-medium	Medium-high	High
Analyzed composition, %						
Dry matter	89.1	89.6	90.4	90.3	89.9	90.4
Crude protein	21.6	22.5	23.9	24.0	22.4	21.0
Calcium	0.84	0.87	0.91	0.80	0.92	0.73
Phosphorus	0.59	0.62	0.65	0.64	0.70	0.63
Ether extract	4.3	4.4	4.9	4.7	4.2	3.9
Ash	4.7	5.4	5.4	5.2	4.8	4.2
Indispensable amino acid, %						
Arginine	1.38	1.28	1.40	1.34	1.27	1.02
Histidine	0.55	0.52	0.58	0.56	0.54	0.47
Isoleucine	0.94	0.96	1.10	1.06	1.01	0.89
Leucine	1.82	1.87	2.32	2.33	2.27	2.18
Lysine	1.42	1.37	1.40	1.36	1.47	1.41
Methionine	0.44	0.44	0.45	0.47	0.55	0.45
Phenylalanine	1.07	1.07	1.26	1.22	1.18	1.06
Threonine	0.91	0.86	0.88	0.87	0.91	0.83
Tryptophan	0.28	0.28	0.28	0.28	0.28	0.25
Valine	1.06	1.04	1.18	1.14	1.08	1.05
Dispensable amino acid, %						
Alanine	1.05	1.14	1.40	1.43	1.39	1.36
Aspartic acid	2.09	2.04	2.29	2.18	2.09	1.73
Cysteine	0.37	0.34	0.38	0.37	0.37	0.32
Glutamic acid	3.69	3.68	4.43	4.37	4.20	3.83
Glycine	0.87	0.82	0.89	0.85	0.81	0.68
Serine	0.92	0.87	0.99	0.97	0.94	0.81
Tyrosine	0.76	0.75	0.87	0.85	0.82	0.71
All amino acids	19.59	19.29	22.06	21.61	21.14	19.00

¹Complete diet samples were taken from 5 feeders per dietary treatment 3 times throughout the study. Samples were stored at -20°C until they were homogenized, subsampled, and submitted to Ward Laboratories, Inc. (Kearney, NE) for proximate analysis, and the University of Missouri Agricultural Experiment Station Chemical Laboratory (Columbia, MO) for amino acid analysis performed in duplicate. Reported values are average of duplicate analysis.

Table 9. Effect of high-lysine sorghum on nursery pig growth performance^{1,2}

Item ³	Corn	Sorghum	High-lysine sorghum				SEM
			Low	Low-medium	Medium-high	High	
BW, lb							
d 0	21.3	21.3	21.3	21.3	21.3	21.3	0.43
d 20	46.0	45.9	47.0	46.2	46.4	45.7	0.73
d 0 to 20							
ADG, lb	1.24	1.23	1.28	1.24	1.26	1.22	0.021
ADFI, lb	1.89	1.88	1.94	1.89	1.92	1.98	0.039
F/G	1.53 ^{ab}	1.53 ^{ab}	1.51 ^b	1.52 ^b	1.53 ^{ab}	1.62 ^a	0.025

¹A total of 293 pigs (DNA Line 241 × 600; initially 21.3 lb) were used in a 20-d experiment with 5 pigs per pen and 10 replications per treatment.

²Values with different superscripts a, b, differ, $P < 0.05$.

³ADG = average daily gain. ADFI = average daily feed intake. F/G = feed-to-gain ratio.